(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 290 274 A1**

(12) # EUROPEAN PATENT APPLICATION

(21) Application number: **88304132.9**

(22) Date of filing: **06.05.88**

(51) Int. Cl.⁴: **A 61 B 5/00**
G 01 N 21/31

(30) Priority: **08.05.87 JP 110465/87**
08.05.87 JP 110472/87

(43) Date of publication of application:
09.11.88 Bulletin 88/45

(84) Designated Contracting States: **DE GB**

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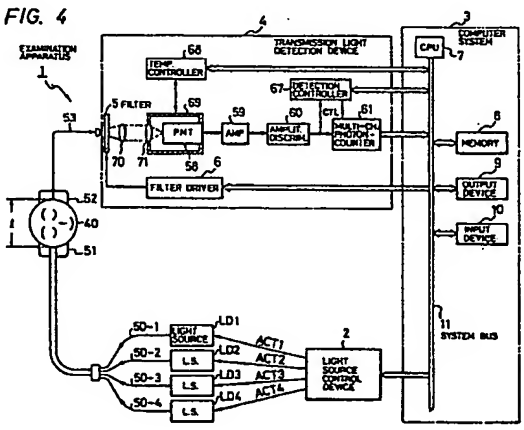
(54) **Examination apparatus for measuring oxygenation.**

(57) An examination apparatus (1) measures oxygenation of objects (40) with near infrared light transmission spectrophotometry. The apparatus includes a plurality of light sources (LD1-LD4) controlled by a light source controller (2, 55) an illumination side fixture (51) for applying the radiation to the object (40), a receiving side fixture (52) for receiving radiation transmitted through the object (40), a transmitted light detection device (4, 22), and a computer system (3, 27) for controlling the system and analysing the output. To adjust automatically a transmitted light quantity to a mangitude suitable for a detection the examination apparatus includes a neutral density filter (5) having a variable transmission factor which is controlled by a driver (6) to set it at its optimum value throughout the measurement or includes a plurality of detection modes (25, 61, Figure 7) and the computer system (22) selects the appropriate detection mode.

FIG. 4



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Description

Examination Apparatus For Measuring Oxygenation

The present invention relates to the apparatus for measuring the oxygen concentration in objects such as organs, e.g. the cerebral tissues, of a human body or animals, especially relates to the apparatus for measuring the oxygenation of hemoglobin in blood and that of cytochrome in cells by detecting their effect on electromagnetic radiation.

In general, in diagnosing the function of the body organ, e.g. the cerebral tissues, it is a fundamental and important parameter whether the oxygen quantity in the body organ is sufficient and it is suitably used. Supplying body organs with sufficient quantity of oxygen is indispensable for the growth ability of foetuses and new-born infants. If the supply of oxygen is insufficient, the death rates of foetuses and new-born infants are high, and even if they live serious problems in body organs may remain as a consequence. The insufficiency of oxygen affects every body organ, especially causes a serious damage in the cerebral tissues.

To examine the oxygen quantity in body organs readily and at the early stage of illness, an examination apparatus disclosed in US-A-4,281,645 has been developed. In this kind of examination apparatus, the variation of oxygen quantity in body organs, especially in the brain is measured through the absorption spectrum of near infrared light in which the absorption is caused by the hemoglobin which is an oxygen-carrying medium in blood and the cytochrome a, a_3 which performs oxydation-reduction reaction in cells. As shown in Fig. 1(a), the absorption spectra of near infrared light (700 to 1300 nm), α_{HbO2} and α_{Hb} by oxygenated hemoglobin (HbO_2) and disoxygenated hemoglobin (Hb), respectively, are different from each other. And as shown in Fig. 1(b), the absorption spectra of that, α_{CyO2} and α_{Cy} by oxidized cytochrome a, a_3 (CyO_2) and reduced cytochrome a, a_3 (Cy), respectively, are different from each other. This examination apparatus utilizes the above-described absorption spectra of near infrared light. Four near infrared light rays with different wavelengths, λ_1, λ_2, λ_3 and λ_4 (e.g. 775 nm, 800 nm, 825 nm and 850 nm) are applied to one side of the patient's head with a time-sharing method and the transmission light rays from the opposite side of the head are in turn detected. By processing these four detected results with the prescribed calculation program, four unknown quantities, i.e. the density variations of oxygenated hemoglobin (HbO_2), disoxygenated hemoglobin (Hb), oxidized cytochrome a, a_3 (CyO_2) and reduced cytochrome a, a_3 (Cy) are calculated and being based on these parameters, for example the variation of a cerebral oxygen quantity is obtained.

Fig. 2 shows a system outline of the above-described conventional examination apparatus 45. The conventional examination apparatus 45 includes; light sources such as laser diodes LD1 to LD4 which emit four near infrared light rays with different wavelengths of λ_1, λ_1, λ_3 and λ_4 respectively; a light source control device 55 which controls output timing of the light sources LD1 to LD4; optical fibers 50-1 to 50-4 which introduces near infrared light rays emitted by the light sources LD1 to LD4 to a patient's head 40; an illumination-side fixture 51 which bundles and holds end portions of the optical fibers 50-1 to 50-4; a detection-side fixture 52 which is fitted to the prescribed position of the opposite side of the patient's head 40; a optical fiber 53 which is held by the detection-side fixture 52 and introduces transmitted near infrared light from the patient's head 40; a transmission light detection device 54 which measures transmission quantity of near infrared light by counting photons of near infrared light introduced by the optical fiber 53; and a computer system 56 which controls the total examination apparatus and determines the variation of oxygen quantity in cerebral tissues being based on the transmission quantity of near infrared light.

The computer system 56 is equipped with a processor 62, a memory 63, output devices 64 such as a display and a printer, and an input device 65 such as a keyboard, and these devices are connected each other by a system bus 66. The light source control device 55 and the transmission light detection device 54 are connected to the system bus 66 as external I/O's.

The light source control device 55 drives the light sources LD1 to LD4 by respective driving signals ACT1 to ACT4 as shown in Figs. 3(a) to 3(d) according to instructions from the computer system 56. As shown in Fig. 3 one measuring period M_k (k = 1, 2, ...) consists of N cycles of CY1 to CYn. At a phase $\varphi n1$ in an arbitrary cycle CYn, no light source of LD1 to LD4 is driven and therefore the patient's head 40 is not illuminated by the near infrared light from the light sources LD1 to LD4. At the phase $\varphi n2$ the light source LD1 is driven and the near infrared light with the wavelength of for example 775 nm is emitted from it. In the same manner, at the phase $\varphi n3$ the light source LD2 is driven and the near infrared light with the wavelength of for example 800 nm is emitted from it; at the phase $\varphi n4$ the light source LD3 is driven and the near infrared light with the wavelength of for example 825 nm is emitted from it; and at the phase $\varphi n5$ the light source LD4 is driven and the near infrared light with the wavelength of for example 850 nm is emitted from it. In this manner the light source control device 55 drives the light sources LD1 to LD4 sequentially with a time-sharing method.

The transmission light detection device 54 is equipped with a filter 57 which adjusts the quantity of near infrared light outputted from the optical fiber 53; lenses 70 and 71; a photomultiplier tube 58 which converts the light from the filter 57 into pulse current and outputs it; an amplifier 59 which amplifies the pulse current from the photomultiplier tube 58; an amplitude discriminator 60 which eliminates the pulse current from the amplifier 59 whose amplitude is smaller than the prescribed threshold value; a multi-channel photon-counter 61 which detects photon frequency in every channel; for example a detection controller 67 which controls detection periods of the multi-channel photon-counter 61; a temperature controller 68 which controls the temperature of a cooler 69 containing the photomultiplier tube 58.

In use of the above-described examination apparatus, the illumination-side fixture and the detection-side fixture are firmly fitted to the prescribed positions of the patient's head 40 by using a tape or the like. After that, the light sources LD1 to LD4 are driven by the light source control device 55 as shown in Figs. 3(a) to 3(d), respectively, so that the four near infrared light rays with different wavelengths are emitted from the light sources LD1 to LD4 sequentially with the time-sharing method, and the light rays are introduced by the optical fibers 50-1 to 50-4 to the patient's head 40. As bones and soft tissues in the patient's head 40 are transparent to the near infrared light, the near infrared light is partially absorbed mainly by hemoglobin in blood and cytochrome a, a_3 in cells and outputted to the optical fiber 53. And the optical fiber 53 introduces the light to the transmission light detection device 54. At the phase $\varphi n1$ no light source of LD1 to LD4 is driven, so that the transmission light detection device 54 does not receive the transmission light originally emitted from the light sources LD1 to LD4. At this phase the transmission light detection device 54 detects dark light.

The photomultiplier tube 58 in the transmission light detection device 54 is the one for photon-counting which has high sensitivity and operates at high response speed. The output pulse current from the photomultiplier tube 58 is sent to the amplitude discriminator 60 through the amplifier 59. The amplitude discriminator 60 eliminates the noise component whose amplitude is smaller than the prescribed amplitude threshold and sends only the signal pulse to the multi-channel photon-counter 61. The multi-channel photon-counter 61 detects photon number only in the periods T_0 which is made synchronized with the driving signals ACT1 to ACT4 for the respective light sources LD1 to LD4 as shown in Figs. 3(a) to 3(d) by a control signal CTL as shown in Fig. 3(e) from the detection controller 67, and counts detected photon number of every light with each wavelength sent from the optical fiber 53. The transmission data of every near infrared light with each wavelength are obtained through the above-described procedure.

That is, as shown in Figs. 3(a) to 3(e), at the phase $\varphi n1$ in the cycle CYn of light source control device 55 no light source of LD1 to LD4 is driven, therefore the dark light data $\underline{d}$ are counted by the transmission light detection device 54. At the phases $\varphi n2$ to $\varphi n5$ the light sources LD1 to LD4 are sequentially driven with the time-sharing method and the transmission light detection device 54 sequentially counts the transmission data $t_{\lambda 1}$, $t_{\lambda 2}$, $t_{\lambda 3}$ and $t_{\lambda 4}$ of the respective near infrared light rays with different wavelengths λ_1, λ_2, λ_3 and λ_4.

The counting of the dark light data $\underline{d}$ and the transmission data $t_{\lambda 1}$, $t_{\lambda 2}$, $t_{\lambda 3}$ and $t_{\lambda 4}$ which is sequentially performed in the cycle CYn, is continued N times from CY1 to CYn. That is, one measuring period M_k ($k = 1, 2, \ldots$) includes N cycles. A concrete example is as follows; if one cycle is 200 μsec and N is 10000, the measuring period M_k becomes 2 sec. At the time of finishing of one measuring period M_k, the counting result of the dark light data D (

$$= \sum_{n=1}^{N} d/CYn)$$

) and the counting results of the transmission data $T_{\lambda 1}$, $T_{\lambda 2}$, $T_{\lambda 3}$ and $T_{\lambda 4}$ (=

$$\Delta T_{\lambda j} = \log [(T_{\lambda j} - D)_{Mk} / (T_{\lambda j} - D)_{Mo}]$$

$$(j = 1 \text{ to } 4). \quad (1)$$

are transferred to the computer system 56 and stored in the memory 63.

The processor 62 performs the subtraction of the dark light component by using the combination of the transmission data and the dark data $(T_{\lambda 1}, T_{\lambda 2}, T_{\lambda 3}, T_{\lambda 4}, D)_{M_K}$ being stored in the memory 63 after one measuring period M_k and the combination of those $(T_{\lambda 1}, T_{\lambda 2}, T_{\lambda 3}, T_{\lambda 4}, D)_{M_o}$ at the start of measuring, and calculates the variation rates of the transmission light $\Delta T_{\lambda 1}$, $\Delta T_{\lambda 2}$, $\Delta T_{\lambda 3}$, and $\Delta T_{\lambda 4}$. That is, the variation rates of the transmission light $\Delta T_{\lambda 1}$, $\Delta T_{\lambda 2}$, $\Delta T_{\lambda 3}$ and $\Delta T_{\lambda 4}$ are calculated as:

$\Delta T_{\lambda j} = \log [T_{\lambda j} - D)_{Mk} / (T_{\lambda j} - D)_{Mo}]$
$(j = 1 \text{ to } 4)$. (1)

The use of logarithm in the above calculation of $\Delta T_{\lambda j}$ is to express the variation as an optical density.

Using the above-calculated variation rates of the transmission light $\Delta T_{\lambda 1}$, $\Delta T_{\lambda 2}$, $\Delta T_{\lambda 3}$ and $\Delta T_{\lambda 4}$, density variations of oxygenated hemoglobin (HbO_2), disoxygenated hemoglobin (Hb), oxidized cytochrome a, a_3 (CyO_2) and reduced cytochrome a, a_3 which are expressed as ΔX_{HbO_2} ΔX_{Hb}, ΔX_{CyO_2} and ΔX_{Cy}, respectively, can be determined. That is, each of density variations of ΔX_{HbO_2} ΔX_{Hb}, ΔX_{CyO_2} and ΔX_{Cy} is calculated as:

$$\Delta X_i = \sum_{j=1}^{4} (\alpha_{ij})^{-1} \Delta T_{\lambda j} / \ell \qquad (2)$$

where α_{ij} is an absorption coefficient of each component i (HbO_2, Hb, CyO_2, Cy) for each wavelength λ_j (λ_1, λ_2, λ_3, λ_4) and is predetermined from Figs. 1(a) and 1(b), and ℓ is the length of the patient's head 40 along the travelling direction of the near infrared light.

As the above-detected density variation components, ΔX_{HbO_2}, ΔX_{Hb}, ΔX_{CyO_2} and ΔX_{Cy}, reflect the variation of oxygen quantity in the brain, the variation of oxygen quantity in the brain can be known by outputting these detected results from the output device 64 and the diagnosis is made being based on these results.

By the way, the transmission quantity of the near infrared light greatly varies in the order of 10^4 to 10^5 with the size of the head 40, that is, the length ℓ of the head 40 in the traveling direction of the near infrared light. Even if it is assumed that the size of the head 40 is kept constant being independent of the patient, as the output powers of the light sources (laser diodes) LD1 to LD4 vary in the order of 101 to 102 with their wavelengths of λ_1, λ_2, λ_3 and λ_4 (775 nm, 800 nm, 825 nm and 850 nm, respectively), the transmission quantities also vary sequentially in the order of 10^1 to 10^2.

On the other hand, it is desired that the light quantity which is made incident on the photomultiplier tube 58 in the transmission light detection device 54 during the measurement should be kept almost constant being independent of the length ℓ of the head 40 and the variation of the output powers of the light sources LD1 to LD4 with the wavelengths, because the dynamic range of the photomultiplier tube 58 is approximately in the order of 10^2.

Therefore, in the conventional examination apparatus 45, a variable light-attenuating ND (Neutral-Density) filter is employed as the filter 57, whose transmission factor can be manually adjusted. When the examination of one object person is started, the transmission factor of the filter 57 and each of the output powers of the light sources LD1 to LD4 are manually adjusted so that the incident light quantity on the photomultiplier tube 58, that is, the transmission light quantity becomes an optimum value.

As described above, the conventional examination apparatus has a problem that because of the manual adjustments of the filter 57 and the output powers of the light sources LD1 to LD4 it is difficult to adjust the transmission light quantity to the optimum value quickly and accurately. In addition, when the near infrared light transmitted from the head 40 is too intense the transmission quantity information incident on the photomultiplier tube 58 is cut off through attenuating the transmission quantity by the filter 57, which prevents the improvement of the measurement accuracy.

Another problem is that as the transmission factor of the filter 57 is kept constant after adjustment at the start of measurement, the variation of the transmission factor during the measurement caused by the position change of the filter 57 cannot be restored. This also prevents the accurate measurement.

According to a first aspect of this invention an examination apparatus for measuring the oxygenation of an object with electromagnetic radiation transmission spectrophotometry, comprising:

plural light sources for emitting electromagnetic radiation at a number of different wavelengths;

light source control means for controlling the plural light sources to sequentially emit electromagnetic radiation;

an illumination-side fixture for contacting electromagnetic radiation generated by the light sources with an object;

a detection-side fixture for receiving electromagnetic radiation transmitted through the object and sending the transmitted electromagnetic radiation to transmitted light detection means;

the transmitted light detection means detecting the transmitted electromagnetic radiation and outputting transmission light data and including filter means with a variable transmission factor; and,

a computer system for controlling the light source control means and the transmitted light detection means for receiving the transmission light data from the transmitted light detection means and for calculating the oxygenation in the object;

is characterised in that:

the transmitted light detection means includes filter driving means for setting the transmission factor of the filter means for attenuating the transmitted electromagnetic radiation; and,

in that the light source control means and the filter driving means control the output powers of the plural light sources and the transmission factor of the filter means respectively, so that the quantity of light output from the filter means is optimised for detection by the transmitted light detection means.

According to a second aspect of this invention an examination apparatus for measuring the oxygenation of an object with electromagnetic radiation transmission spectrophotometry, comprising:

light source means for emitting electromagnetic radiation at a number of different wavelengths;

light source control means for controlling the light source means so as to sequentially emit the electromagnetic radiation;

an illumination-side fixture for contacting the electromagnetic radiation generated by the light source means with an object;

a detection-side fixture for detecting electromagnetic radiation transmitted through the object and sending

the transmitted electromagnetic radiation to transmitted light detection means;

the transmitted light detection means detecting the transmitted electromagnetic radiation with a photomultiplier tube and outputting transmission light data; and,

a computer system for controlling the light source control means and the transmission light detection means, and for receiving the transmission light data from the transmission light detection means and calculating the oxygenation in the object;

is characterised in that

the transmitted light detection means has a plurality of detection modes and detects the transmitted electromagnetic radiation with the appropriate detection mode for the intensity of the transmitted electromagnetic radiation.

The present invention provides an examination apparatus which can adjust quickly and accurately to differences in the basic light transmission characteristics of the object and thereby obtains a more accurate measurement result.

Particular embodiments of examination apparatus in accordance with this invention will now be described with reference to the accompanying drawings; in which:-

Figures 1(a) and 1(b) are graphs showing the absorption spectra of hemoglobin and cytochrome, respectively;

Figure 2 is a block diagram of a conventional examination apparatus;

Figures 3(a) to 3(d) are timing-charts of driving signals ACT1 to ACT4 and a control signal CTL, respectively;

Figure 4 is a block diagram of a first embodiment of an examination apparatus according to the present invention;

Figure 5 is a perspective view of a filter and a filter driver;

Figure 6 is a block diagram of another filter and a filter driver; and,

Figure 7 is a block diagram of a second embodiment of an examination apparatus according to the present invention.

The first aspect of the present invention will be described in the following.

Figure 4 is a block diagram showing a system constitution of an examination apparatus according to the first aspect of the invention. The same blocks, parts or signals in Figure 4 as those in Figure 2 are designated by the same reference numerals or numbers as those in Figure 2, and the explanation of those will be omitted.

A light control device 2 of an examination apparatus 1 in Fig. 4 automatically controls output powers of light sources LD1 to LD4 according to an instruction from a computer system 3 so that transmission quantities of near infrared light rays to be detected by a transmission light detection device 4 become optimum not depending on wavelengths λ_1, λ_2, λ_3 and λ_4.

A filter driver 6 in the transmission light detection device 4 controls a transmission factor of a filter 5 within its variable range of transmission factor according to an instruction from the computer system 3 so that the light quantity incident on a photomultiplier tube 58 does not vary even if sizes of heads 40, that is, lengths ℓ of heads 40 vary from one object person to another. The computer system 3, in the same manner as in the conventional computer system 56, has a constitution that a processor 7, a memory 8, an output device 9 and input device 10 are connected to a system bus 11. Furthermore, the computer system controls the light source control device 2 so that the light source control device 2 automatically controls the output powers of the light sources LD1 to LD4, and also controls the filter driver 6 so that the filter driver 6 automatically adjusts the transmission factor of the filter 5.

The operation of the above-described examination apparatus will be described in the following. In the period M_o of the beginning of measurement, at phases n2 to φn5 in one cycle CYn the light sources LD1 to LD4 are sequentially driven in a time-sharing method and transmission light quantity data $t_{\lambda 1}$, $t_{\lambda 2}$, $t_{\lambda 3}$ and $t_{\lambda 4}$ of the near infrared light rays with respective four different wavelengths of λ_1, λ_2, λ_3 and λ_4 are sequentially counted in the transmission light detection device 4. In the same procedure, the transmission light quantity data $t_{\lambda 1}$, $t_{\lambda 2}$, $t_{\lambda 3}$ and $t_{\lambda 4}$ which are sequentially counted in a cycle CYn are continuously counted over N cycles (CY1 to CYN) in the period M_o of the beginning of measurement. After the measurement of the Nth cycle CYN, the counted results $(T_{\lambda 1}, T_{\lambda 2}\ T_{\lambda 3}, T_{\lambda 4})_{Mo}$ are transferred to the computer system 3 and stored in the memory 8. The processor 7 judges whether each of the transmission quantity data $(T_{\lambda 1}, T_{\lambda 2}, T_{\lambda 3}, T_{\lambda 4})_{Mo}$ is optimum, or not. Furthermore, the processor 7 judges whether the transmission quantity data $T_{\lambda 1}$ to $T_{\lambda 4}$ are different from one another (with wavelength), or not.

If the computer system 3 judges that the transmission quantity data $T_{\lambda 1}$ to $T_{\lambda 4}$ are not optimum, it makes the filter driver 6 operate so as to change the transmission factor of the filter 5 by an appropriate amount and also changes the output powers of the light sources LD1 to LD4 by an appropriate amount. Furthermore, if the transmission quantity data $T_{\lambda 1}$ to $T_{\lambda 4}$ are different from one another, the computer system 3 changes the transmission factor of the filter 5 and the output powers of the light sources LD1 to LD4 with wavelengths so as to eliminate the variation in the transmission quantity data. The optimum transmission factors and the optimum output powers of the light sources LD1 to LD4 at every wavelength which have been obtained in the above procedure, are stored in the memory 8.

The optimum transmission factors and the output powers of the light sources LD1 to LD4 at every wavelength which were stored in the memory 8 in the period M_o of the beginning of measurement, are used in the actual measurement of the oxygenation to automatically control the transmission factor of the filter 5 and

the output powers of the light sources LD1 to LD4. That is, in a subsequent measuring period M_k (k = 1, 2, ...), when the transmission quantity data are measured at phases φn2 to φn5 in a cycle CYn the processor 7 changes the transmission factor of the filter 5 and the output powers of the light sources LD1 to LD4 on the basis of the optimum transmission factor and the optimum output powers at every phase which are stored in the memory 8. In this procedure the cerebral oxygenation can be measured with sequentially changing the transmission factor of the filter 5 and the output powers of the light sources LD1 to LD4 automatically so as to make the transmission quantities optimum.

Fig. 5 illustrates an embodiment of the filter 5 and the filter driver 6 shown in Fig. 4. A filter 5-1 in Fig. 5 is a ring-like ND (Neutral-Density) filter whose transmission factor gradually varies along its circumference. The filter 5-1 is driven in the rotational direction by a motor 6-1. If a portion PS1 of the filter 5-1 with a minimum transmission factor is located in the optical axis, the light quantity of the near infrared light which is to be made incident on the photomultiplier tube 58 is attenuated most. On the other hand, if a portion PS2 with a maximum transmission factor is located in the optical axis, the light quantity of the near infrared light which is to be made incident on the photomultiplier tube 58 is attenuated least. The motor 6-1 is for example a pulse motor and controlled by the computer system 3.

With the constitutions of the filter 5-1 and the motor 6-1 as shown in Fig. 5, even if the length ℓ, of the head 40 varies with the object persons, the computer system 3 can locate the portion of the filter 5-1 with the appropriate transmission factor in the optical axis by rotating the filter 5-1 by the appropriate amount by the motor 6-1 in the manner as described above.

As the transmission factor can be automatically determined with the simple mechanism without a manual operation as described in the foregoing, the manipulation of the examination apparatus become much easier.

However, as the filter 5-1 is mechanically rotated by the motor 6-1 in the above embodiment, it may be expected in the long use that the accuracy in positioning the appropriate portion of the filter 5-1 in the optical axis, and accuracy in other parts may be deteriorated and thereby the reliability of the examination data may be decreased. Moreover, as mechanical parts are used, the above embodiment is not suitable to miniaturize the examination apparatus. Further disadvantage is that much electric power is dissipated by the motor 6-1.

Fig. 6 shows another embodiment of the filter and the filter driver which can further improve the reliability of the examination apparatus and can miniaturize the examination apparatus.

A filter 5-2 in Fig. 6 consists of a liquid crystal panel. As the light-attenuating factor of a liquid crystal panel varies with an applied voltage, the transmission factor of the filter 5-2 can be made variable by using this characteristics of a liquid crystal panel.

The filter 5-2 consisting of the liquid crystal panel is connected to the driving section 6-2 which applies a driving voltage to the filter 5-2. The driving section 6-2 comprises a conversion part 12 which converts a control signal from the computer system 3 into a transmission factor, and a driving circuit 13 which applies the driving voltage corresponding to the transmission factor converted by the conversion part 12 to the filter 5-2.

The conversion part 12 converts the control signal sent from the computer system 3 into the transmission factor which is for example proportional to the amplitude of the control signal. In this case, as the driving voltage applied to the filter 5-2 consisting of the liquid crystal panel is proportional to the amplitude of the control signal from the computer system 3, the light-attenuating factor of the filter 5-2 can be linearly varied by varying the amplitude of the control signal by the computer system 3. If the conversion part 12 converts the control signal from the computer system into the transmission factor non-linearly, the resultant light-attenuating factor of the filter 5-2 varies non-linearly to the variation of the control signal which is determined by the computer system.

As described above, as there is no part which is mechanically controlled when the liquid crystal panel is employed as the filter 5-2, the reliability of the examination apparatus does not decrease even in the long use, the examination apparatus can be miniaturized, and the electric power dissipated in the examination apparatus can be reduced.

The second aspect of the invention will be described in the following.

Fig. 7 shows a system constitution of an examination apparatus according to the second aspect of the invention. The same blocks, parts or signals in Fig. 7 as those in Fig. 2 are designated by the same reference numerals or numbers as those in Fig. 2 and the description of those will be omitted.

In an examination apparatus 21 in Fig. 7, a transmission light detection device 22 is equipped with a detection controller 23 which controls a detection period of a multi-channel photon-counter 61 and adjusts the gain of a photomultiplier tube 58 by controlling a voltage applied to the photomultiplier tube 58. More specifically, the detection controller 23 controls the detection period of the multi-channel photon-counter 61 according to an instruction from a computer system 22 and also adjusts the voltage applied to the photomultiplier tube 58 according to an amplitude of current which is obtained through photoelectric conversion by the photomultiplier tube 58, amplification by an amplifier 59 and amplitude discrimination by an amplitude discriminator 60. The voltage applied to the photomultiplier tube 58 is adjusted through a control signal CTL'.

In this embodiment, the transmission factor of a filter 24 is set on the basis of the case in which the light quantity of the transmission light is minimum. Therefore, when the light quantity of the transmission light introduced by an optical fiber 53 is small, an prescribed quantity of the transmission light is made incident on the photomultiplier tube 58, a pulse current is outputted from the photomultiplier tube 58, and the detection controller 23 controls the voltage applied to the photomultiplier tube 58 (that is, the gain of the photomultiplier

tube) on the basis of the pulse current so that the photomultiplier tube 58 operates with a "photon-counting mode". On the other hand, when the light quantity of the transmission light is large, a large quantity of the transmission light is made incident on the photomultiplier tube 58 and an analog current is outputted from the photomultiplier tube 58. The detection controller 23 controls the gain of the photomultiplier tube 58 on the basis of the analog current so that the photomultiplier tube 58 operates with an "analog detection mode".

The transmission light detection device 22 of the examination apparatus 21 in Fig. 7 is equipped with the multi-channel photon-counter 61 which is the same as the conventional one and counts in a digital method the number of pulse currents (that is, the number of photons) outputted from the photomultiplier tube 58 when the transmission light quantity incident on the photomultiplier tube 58 is small, and also equipped with an analog detector 25 which detects the analog current outputted from the photomultiplier tube 58 when the transmission light quantity incident on the photomultiplier tube 58 is large. The selection of the device for detecting the output current from the photomultiplier tube 58 from the multi-channel photon-counter 61 and the analog detector 25 is made by changing over of switch SW through a selection signal SL. the analog detector 25 has a wide dynamic range and the analog current detected by the analog detector 25 is sent to the computer system 27 after being A/D-converted by an A/D converter 26.

In the computer system 27, a processor 28, a memory 29, an output device 30 and an input device 31 are connected to a system bus 32 in the same manner as in the conventional computer system 56. Furthermore, the computer system 27 has a function to control the detection controller 23 as described above.

In the examination apparatus 21 with the above-described constitution, as the transmission factor of the filter 24 is previously set on the basis of the case with the minimum light quantity of the transmission light introduced by the optical fiber 53, the light quantity of the transmission light incident on the photomultiplier tube 58 greatly varies depending on the size of the head 40 or the variation in the absorption quantity by the head 40 with the wavelength. Therefore, it is necessary before the actual oxygenation measurement to initially test whether the transmission light quantity is small and the photomultiplier tube 58 is operating with the photon-counting mode, or the transmission light quantity is large and the photomultiplier tube 58 is operating with the analog detection mode.

This initial test can be performed in the period M_o of the beginning of the examination. At the phase $\varphi n2$ in one cycle CYn in the period M_o, the near infrared light with the wavelength of λ_1 is emitted from the light source LD1 and the transmission light with the wavelength of λ_1 from the head 40 is made incident on the photomultiplier tube 58 through the filter 24. The output current corresponding to the transmission light quantity is outputted from the photomultiplier tube 58 and sent to the detection controller 23.

In the same manner, at the phases $\varphi n3$, $\varphi n4$ and $\varphi n5$ in one cycle CYn in the period M_o the near infrared light rays with the respective wavelengths of λ_2, λ_3 and λ_4 are sequentially emitted from the respective light sources LD2, LD3 and LD4. And the transmission light rays with the wavelengths of λ_2, λ_3 and λ_4 from the head 40 are sequentially made incident on the photomultiplier tube 58 through the filter 24 in a time-sharing method. The output currents corresponding to the respective transmission light quantities are outputted from the photomultiplier tube 58 and sent to the detection controller 23. In this procedure, on the basis of the output currents at every wavelength outputted over prescribed times of cycles CYl to CYN in the period M_o of the beginning of the examination, the detection controller 23 judges whether the output currents correspond to the photon-counting mode or the analog detection mode. The result of this judgment is stored in the memory 29 of the computer system 27. The initial setting of the detection modes at every wavelength is completed with the foregoing procedure.

The detection modes initially set for every wavelength of λ_1 to λ_4 are used in each of the cycles CY1 to CYN in the measuring period M_k in which the actual oxygenation measurements are performed. That is, at the phase $\varphi n2$ in the cycle CYn in the measuring period M_k, the detection controller 23 gets the detection mode initially set for the wavelength λ_1 out of the memory 29, adjusts the gain of the photomultiplier tube 58 through the control signal CTL' according to this detection mode, and changes over the switch SW through the selection signal SL. For example, if the detection mode for the wavelength of λ_1 stored in the memory 29 is the photon-counting mode, the detection controller adjusts the gain of the photomultiplier tube 58 to the value suitable for the photon-counting mode and changes over the switch SW to the multi-channel photon-counter 61.

At other phases $\varphi n3$, $\varphi n4$ and $\varphi n5$ in the cycle CYn, the detection controller 23 gets the detection modes initially set for the respective wavelengths λ_2, λ_3 and λ_4 out of the memory 29, adjusts the gain of the photomultiplier tube 58 through the control signal CTL' according to these detection modes, and changes over the switch SW through the selection signal SL.

As described in the foregoing, as the transmission light quantity can be measured with the appropriate detection mode corresponding to the transmission light quantity incident on the photomultiplier tube 58, it is not necessary to cut off the information of the transmission quantity even when the transmission quantity is large and thereby the accurate measurement results can be obtained.

Though in the foregoing embodiment the detection modes are initially set in the period Mo of the beginning of the examination, without performing the initial setting of the detection modes the transmission light quantity may be detected with both detection modes regardless of the magnitude of the transmission light quantity by changing over the photon-counting mode and the analog detection mode within one phase with the time-sharing method. In this case, two kinds of the transmission quantity data which are detected with the photon-counting mode and the analog detection mode are stored in the memory 29 at the end of the one

measuring period M_k. The processor 28 judges which data are appropriate, selects the appropriate data, and outputs the selected data to the output device 30.

Though the foregoing embodiments are described with four light sources of LD1 to LD4, the number of the light sources is not limited to four, but may be two or more than four.

Moreover, though the foregoing embodiments are described with plural light sources, the electromagnetic waves with different wavelengths may be obtained by using only one white light source and filtering the white light emitted from the white light source. The application of the examination apparatus according to the invention is not limited to the medical field, but covers many fields including mere measurements. The measuring object is not limited to body organ, but may be general object such as a piece of flesh. Furthermore, the electromagnetic wave emitted from the light source is not limited to the near infrared light, but may be far infrared light, visible light, or microwave.

Claims

1. An examination apparatus (1) for measuring the oxygenation of an object (40) with electromagnetic radiation transmission spectrophotometry, comprising:

plural light sources (LD1-LD4) for emitting electromagnetic radiation at a number of different wavelengths;

light source control means (2) for controlling the plural light sources (LD1-LD4) to sequentially emit electromagnetic radiation;

an illumination-side fixture (51) for contacting electromagnetic radiation generated by the light sources (LD1-LD4) with an object (40);

a detection-side fixture (52) for receiving electromagnetic radiation transmitted through the object (40) and sending the transmitted electromagnetic radiation to transmitted light detection means (4);

the transmitted light detection means (4) detecting the transmitted electromagnetic radiation and outputting transmission light data and including filter means (5) with a variable transmission factor; and,

a computer system (3) for controlling the light source control means (2) and the transmitted light detection means (4) for receiving the transmission light data from the transmitted light detection means and for calculating the oxygenation in the object (40);

characterised in that:

the transmitted light detection means (4) includes filter driving means (6) for setting the transmission factor of the filter means (5) for attenuating the transmitted electromagnetic radiation; and,

in that the light source control means (2) and the filter driving means (6) control the output powers of the plural light sources (LD1-LD4) and the transmission factor of the filter means (5) respectively, so that the quantity of light output from the filter means (5) is optimised for detection by the transmitted light detection means (4).

2. An examination apparatus as claimed in claim 1, wherein optimum output powers of the respective light sources (LD1-LD4) and optimum transmission factors for the electromagnetic radiation with different wavelengths are previously determined at the beginning of the measurement and stored in the computer system (3), and the light source control means (2) and the filter driving means (6) control the output powers of the plural light sources (LD1-LD4) and the transmission factor of the filter means (5) on the basis of the optimum ouput powers and the optimum transmission factors stored in the computer system (3) respectively, in the oxygenation measurement.

3. An examination apparatus as claimed in clam 1 or 2, wherein

the filter means (5) is a ring-shaped neutral density filter (5-1) whose transmission factor varies around its circumference; and,

the filter driving means (6) is a motor (6-1) which sets the transmission factor of the ring-shaped neutral density filter (5-1) by rotating the filter (5-1) to locate an appropriate portion of it in the optical axis of the output of the detection-side fixture (52) in accordance with an instruction from the computer system (3).

4. An examination apparatus as claimed in claim 1 or 2, wherein

the filter means (5) is a liquid crystal panel (5-1) whose transmission factor varies with an applied driving voltage; and,

the filter driving means (6-2) receives a control signal from the computer system (3), converts the control signal into a transmission factor signal, and applies an appropriate driving voltage corresponding to the transmission factor signal to the liquid crystal panel (5-2).

5. An examination apparatus as claimed in any preceding claim, wherein the transmitted light detection means (22) detects the transmitted electromagnetic radiation with a photomultiplier tube (58), has a pluraltiy of detection modes, and detects the transmitted electromagnetic radiation with the appropriate mode for the intensity of the transmitted electromagnetic radiation.

6. An examination apparatus (21) for measuring the oxygenation of an object with electromagnetic radiation transmission spectrophotometry, comprising:

light source means (LD1-LD4) for emitting electromagnetic radiation at a number of different wavelengths;

light source control means (55) for controlling the light source means (LD1-LD4) so as to sequentially emit the electromagnetic radiation;

an illumination-side fixture (51) for contacting the electromagnetic radiation generated by the light source means (LD1-LD4) with an object (40);

a detection-side fixture (52) for detecting electromagnetic radiation transmitted through the object (40) and sending the transmitted electromagnetic radiation to transmitted light detection means (22);

the transmitted light detection means (22) detecting the transmitted electromagnetic radiation with a photomultiplier tube (58) and outputting transmission light data; and,

a computer system (27) for controlling the light source control means (55) and the transmission light detection means (22), and for receiving the transmission light data from the transmission light detection means (22) and calculating the oxygenation in the object (40);

characterised in that

the transmitted light detection means (22) has a plurality of detection mdoes and detects the transmitted electromagnetic radiation with the appropriate detection mode for the intensity of the transmitted electromagnetic radiation.

7. An examination apparatus as claimed in claim 5 or 6, wherein the transmitted light detection means (22) further includes a photon-counter (61) and an analogue detector (25) for detecting an output current from the photomultiplier tube (58); and,

the output current from the photomultiplier tube (58) is detected by the photon-counter (61) in a photon-counting mode when the transmitted light quantity incident on the photomultiplier tube (58) is small, or is detected by the analogue detector (25) in an analogue detection mode when the transmitted light quantity is large.

8. An examination apparatus as claimed in claim 5, 6 or 7, wherein the transmitted light detection means (22) further includes a detection controller (23) for receiving the output current from the photomultiplier tube (58) and for selecting the detection mode and controlling a voltage applied to the photomultiplier tube (58) in accordance with the received output current.

9. An examination apparatus as claimed in claim 5, 6 or 7, wherein appropriate detection modes for the respective electromagnetic radiation of different wavelengths are previously determined at the beginning of the measurement and stored in the computer system (27), and the computer system (27) controls the transmitted light detection means (22) on the basis of the stored appropriate detection modes so that the detection mode is appropriately selected during the oxygenation measurement.

10. An examination apparatus as claimed in claim 7 or claim 8 or 9 when dependent upon claim 7, wherein the output current from the photomultiplier tube is detected by both the photon-counter (61) and the analogue detector (25) for the electromagnetic radiation of different wavelength, and the computer system (22) selects the appropriate transmission light data from transmission light data obtained in both the photon-counting the analogue detection mode.

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FIG. 1(a)

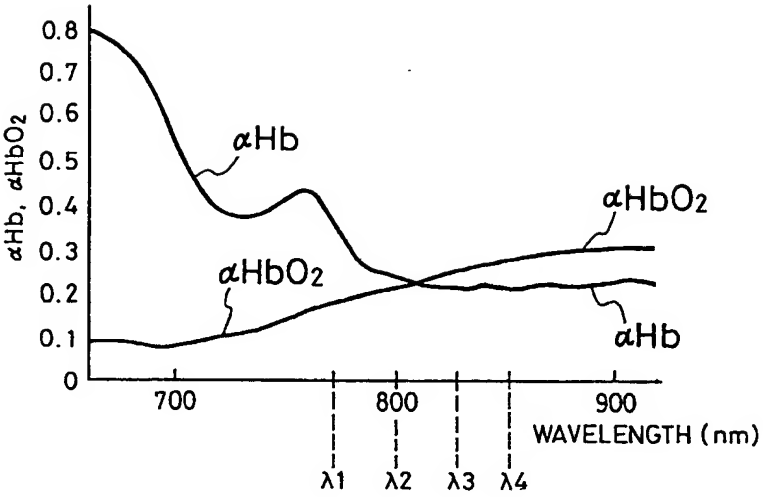
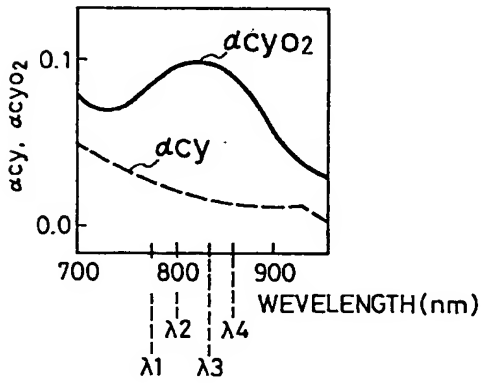


FIG. 1(b)



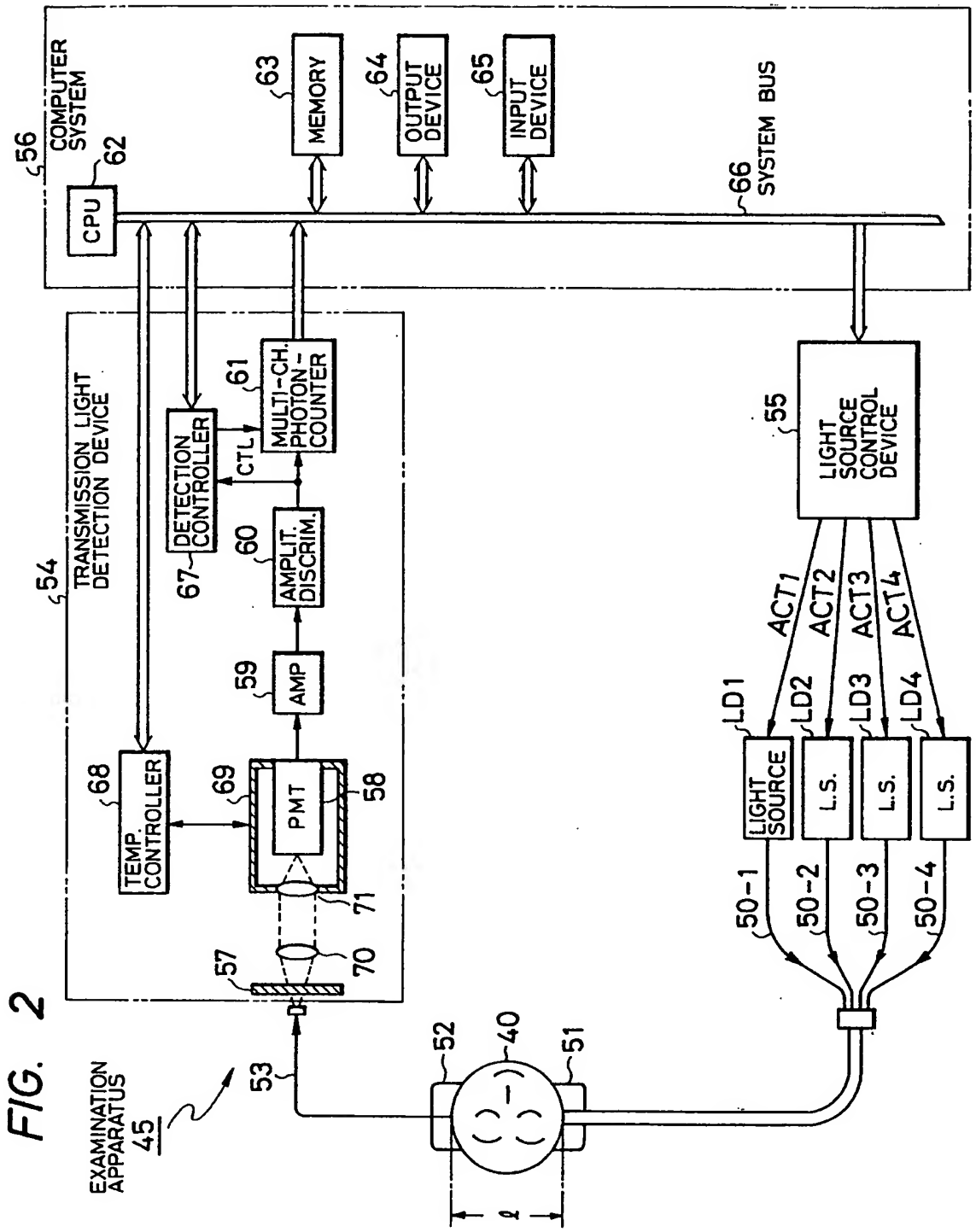

COMPUTER SYSTEM
56
CPU
62
63
MEMORY
64
OUTPUT DEVICE
65
INPUT DEVICE
66
SYSTEM BUS
TRANSMISSION LIGHT DETECTION DEVICE
54
DETECTION CONTROLLER
67
CTL
MULTI-CH. PHOTON-COUNTER
61
AMPLIT. DISCRIM.
60
AMP
59
TEMP. CONTROLLER
68
69
PMT
58
71
70
57
LIGHT SOURCE CONTROL DEVICE
55
ACT1
ACT2
ACT3
ACT4
LD1
LD2
LD3
LD4
LIGHT SOURCE
L.S.
L.S.
L.S.
50-1
50-2
50-3
50-4
52
40
51
53
EXAMINATION APPARATUS
45
ℓ

FIG. 2

FIG. 3

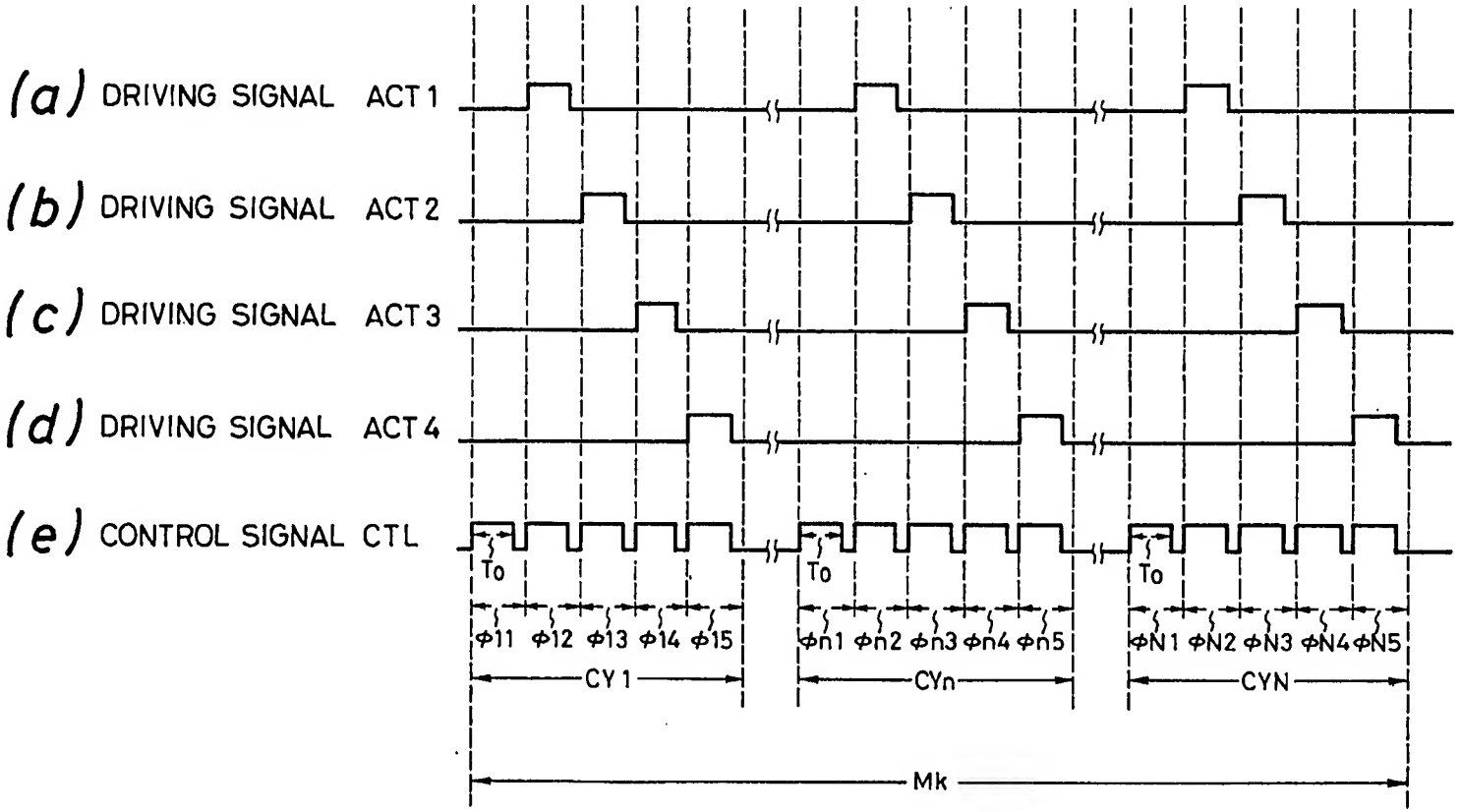


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FIG. 4

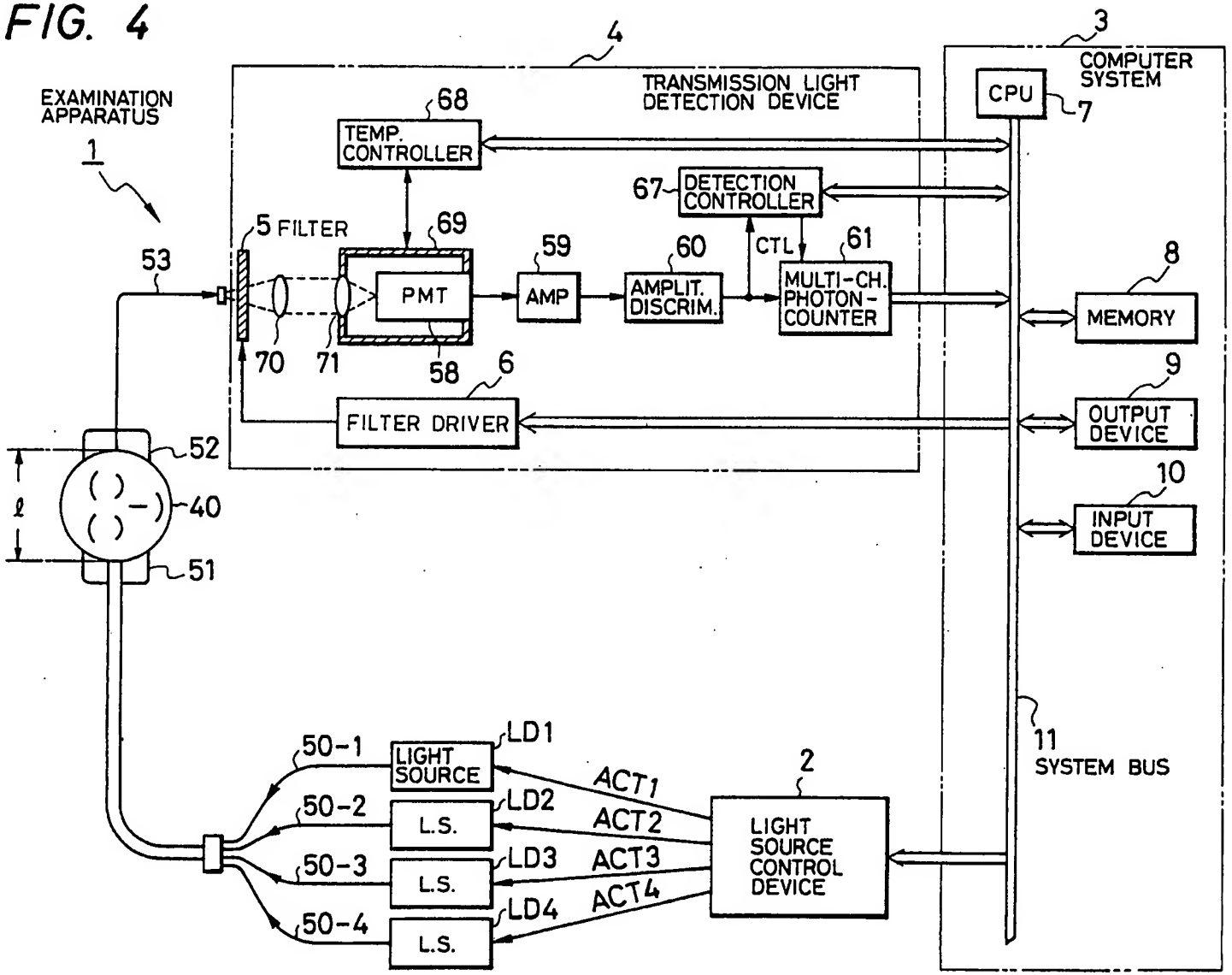

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FIG. 5

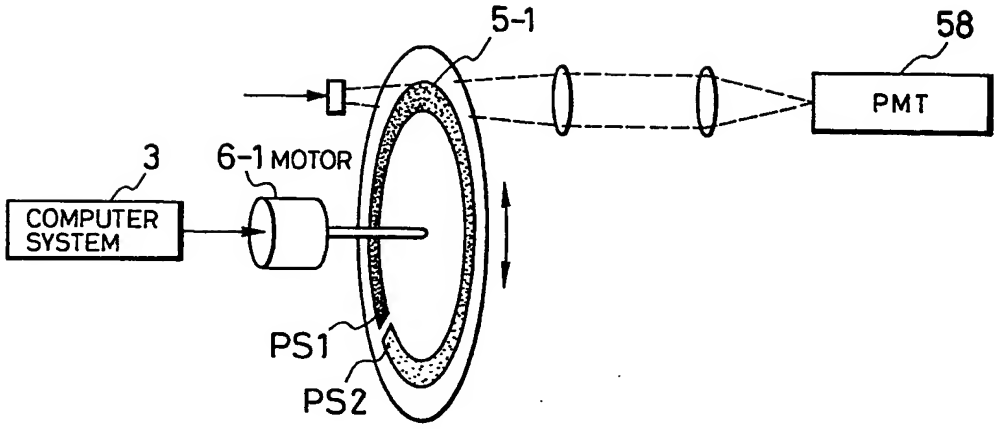
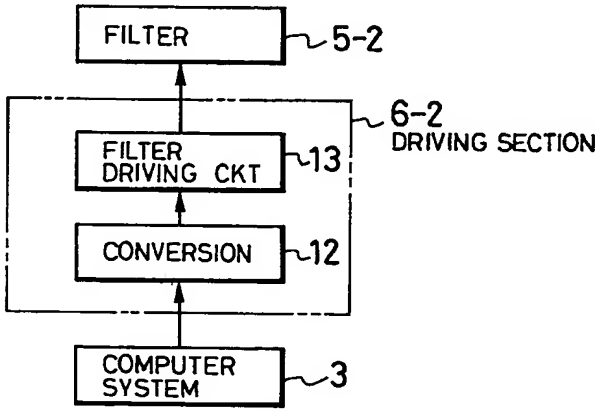

5-1
58
PMT
3
6-1 MOTOR
COMPUTER SYSTEM
PS1
PS2

FIG. 6


FILTER
5-2
6-2
DRIVING SECTION
FILTER DRIVING CKT
13
CONVERSION
12
COMPUTER SYSTEM
3

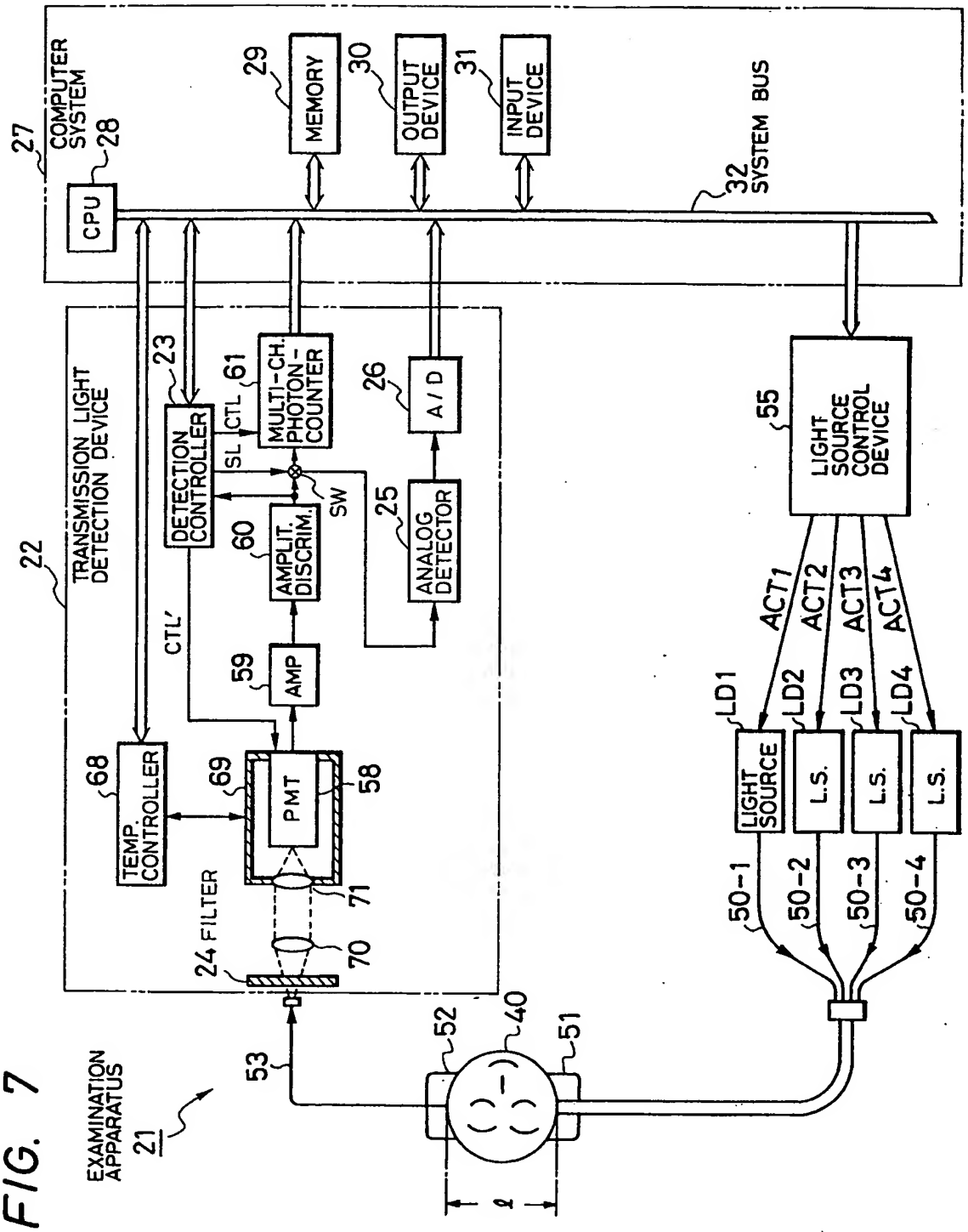

EXAMINATION APPARATUS
21
COMPUTER SYSTEM
27
CPU
28
MEMORY
29
OUTPUT DEVICE
30
INPUT DEVICE
31
SYSTEM BUS
32
TRANSMISSION LIGHT DETECTION DEVICE
22
DETECTION CONTROLLER
23
MULTI-CH. PHOTON-COUNTER
61
A/D
26
AMPLIT. DISCRIM.
60
ANALOG DETECTOR
25
AMP
59
PMT
58
TEMP. CONTROLLER
68
69
FILTER
24
70
71
CTL
SL
SW
CTL'
LIGHT SOURCE CONTROL DEVICE
55
ACT1
ACT2
ACT3
ACT4
LD1
LD2
LD3
LD4
LIGHT SOURCE
L.S.
L.S.
L.S.
50-1
50-2
50-3
50-4
53
52
40
51
ℓ

FIG. 7

European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 88 30 4132

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
Y,D	GB-A-2 075 668 (DUKE UNIVERSITY) * Whole document *	1	A 61 B 5/00 G 01 N 21/31
Y	PATENT ABSTRACTS OF JAPAN, vol. 11, no. 79 (P-555)[2526], 11th March 1987; & JP-A-61 237 040 (HOSU K.K.) 22-10-1986 * Abstract *	1	
A	IDEM	3	
A	EP-A-0 102 816 (NELLCOR INCORPORATED) * Abstract *	1	
A	US-A-3 794 425 (V.N. SMITH et al.) * Column 1, lines 6-9,39-55; column 2, lines 4-67; figure 1 *	1-3	
A	EP-A-0 075 171 (MILES LABORATORIES INC.) * Abstract; page 4, line 16 - page 5, line 30; figure 1 *	4	
A	GB-A-2 143 319 (H. RITZL) * Whole document *	5,6,8, 10	TECHNICAL FIELDS SEARCHED (Int. Cl.4) A 61 B G 01 N G 01 J
A	JOURNAL OF APPL. SPECTROSCOPY, vol. 18, no. 3, January 1975, pages 349-353, Plenum Publishing Corp., New York, US; L.I. KOMAROV et al.: "Recording variable radiation by discrete-photon counting method" * Whole article *	7,10	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	27-07-1988	FERRIGNO, A.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
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T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

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